UNITED STATES ATOMIC ENERGY COMMISSION

UCRL-626

EXPERIMENTS ON N-P SCATTERING WITH 260-MEV NEUTRONS

By
E. Kelley E. Segre
C. Leith C. Wiegand

March 6, 1950

University of California
Radiation Laboratory

Technical Information Division, ORE, Oak Ridge, Tennessee

EXPERIMENTS ON N-P SCATTERING WITH 260 MEV NEUTRONS

E. Kelly, C. Leith, E. Segre and C. Wiegand
Radiation Laboratory, Department of Physics, University of California
Berkeley, California

March 6, 1950

Abstract

Neutrons produced by 350 Mev protons impinging on beryllium are scattered by hydrogen. We measure the differential scattering cross section as a function of the scattering angle. Results are summarized in Fig. 3 of the paper.

EXPERIMENTS ON N-P SCATTERING WITH 260 MEV NEUTRONS

E. Kelly, C. Leith, E. Segre and C. Wiegand

Radiation Laboratory, Department of Physics, University of California
Berkeley, California

March 6, 1950

I Introduction

When the circulating proton beam of the 184-inch cyclotron is intercepted by a beryllium target at a radius of 81 inches, high energy neutrons are produced with an energy distribution maximum at about 260 Mev. Using this neutron beam with a low energy cutoff at 200 Mev we have performed n-p scattering experiments similar to those previously done with neutrons of 40 and 90 Mev mean energies.(1)

The methods and apparatus used will in general be described only where they differ from those of the previous work and the reader is referred to the earlier paper for the missing details and for notation.(2) The principle of the experiment is to measure the number of protons scattered from an hydrogenous target into a fixed solid angle $d\Omega = d\Psi d \cos \Phi$ at angle Φ; this number is proportional to the differential cross section $\sigma(\Phi)$. From this we find the differential cross section $\sigma(\theta) = \sigma(\Phi)\,(d \cos \Phi / d \cos \theta)$ in the center of gravity system. The direct measurement of $\sigma(\Phi)$ is not on an absolute scale, but we can normalize it and pass to an absolute scale by requiring that

$$\int \sigma(\Phi)\, d\Omega = \text{total scattering cross section} = \sigma_t$$

---

(1) J. Hadley, E. Kelly, C. Leith, E. Segre, C. Wiegand and H. York, Phys. Rev. 75, 351 (1949); hereinafter referred to as NP-I.

(2) In formula (5) of NP-I Θ should be replaced by Φ; in the sixth line, first column of page 361 $d \cos \Omega / d \cos \theta$ should be replaced by $d \cos \Phi / d \cos \theta$; and the formula of the second column of page 361 should read $V(r) = (g^2/r)\, e^{-Kr}\, (1 + P/2)$

In practice polyethylene was used for the hydrogenous target and the effect of the carbon was measured (using graphite) and subtracted.

The main results of the investigation are given in Tables I and II and Fig. 3. These results have been communicated in a preliminary form to Messrs. R. S. Christian and E. W. Hart and they have taken them into account in a theoretical paper endeavoring to interpret all n-p scattering data through a suitable potential. We refer to that paper for their theoretical treatment of the data.(3)

II Apparatus

The arrangement of apparatus shown in Fig. 1 was used for all angles Φ. The diameter of the last counter has been increased to 5.1 cm and absorber A has been changed to the appropriate thickness of tungsten to give a primary neutron beam cutoff at an energy of 200 Mev; otherwise this apparatus is the same as apparatus A previously described in NP-I. The equipment was checked by all the performance tests described in section II.E of NP-I. The approximate angular resolution of the telescope is 3°. The error in the value of $\sigma(\Phi)$ introduced by this lack of resolution is significant only for the value measured at $\Phi = 0$; here we estimate this effect would put the true cross section possibly 10 percent above the observed value (we have not made this correction to the data).

III Effect of Absorber A

The thickness of absorber A required to give a 200 Mev energy cutoff of the primary neutron beam (approximately 12 cm of Al or 4.5 cm of Pb at small angles) causes losses of the coincidence counting rate of the recoil protons, the variation of which losses with Φ is not small. These losses are due primarily to nuclear interaction, both elastic and

(3) R. S. Christian and E. W. Hart, Phys. Rev. 77, 441 (1950)

inelastic, and to multiple small angle Rutherford scattering; estimates of the losses indicated tungsten to be the most suitable material for absorber A and accordingly tungsten was used. It is not possible to calculate these losses accurately due in part to lack of data and in part to the poorly defined geometry of the sensitive region of the counter behind absorber A.

To get an empirical measure of the loss due to absorber A we made the following investigation. The telescope was placed in the external deflected proton beam, the diameter of which was larger than that of the counters, and the attenuation of the telescope coincidence counting rate was measured for various thicknesses of tungsten placed in the position of absorber A.

This was done as follows: in order to determine the number of incident protons an extra counter tube was placed in front of the telescope and electronically connected in triple coincidence with the first two counter tubes of the regular telescope. This electronic connection did not influence the operation of the regular telescope. In order to verify the voltage plateaus of the two systems of three counters the extra counter tube was desensitized by lowering its voltage so as to make it the controlling counter of the monitor coincidence circuit; the voltage on the regular telescope was then varied and in this way we could verify that the regular telescope was operating on a voltage plateau. Next the sensitivity of the extra counter tube was increased until it had the same sensitivity as the others and this was confirmed by the fact that, with no tungsten absorber, the regular telescope coincidence counting rate was 0.98 of the monitor coincidence counting rate. Finally the attenuation measurements were made.

The attenuation due to the tungsten was found to be approximately linear with the thickness of the tungsten, ending in a sharp cutoff which gave the range of the proton beam. Data were taken at proton beam energies corresponding to ranges in tungsten of 109, 58, 38 and 24 gm cm^{-2}. (The energy of the proton beam was varied by placing Al absorbers between the magnetic deflector and the focussing magnet of the cyclotron beam deflecting system). On the basis of these data and the energy distribution of the neutron beam given in the next section, the attenuation due to absorber A was computed. Corrections for this have been applied to the differential cross sections given in Tables I and II and Fig. 3; the values of the transmission of absorber A are listed in Table I. We estimate these attenuation values to be good to about 10 percent.

IV Neutron Beam

The neutron beam was produced by intercepting the circulating beam of 350 Mev protons with a 5.08 cm thickness of beryllium. The beam was collimated in the forward direction by a hole in the 10 foot thick concrete walls of the cyclotron shield and emerged through an aperture whose diameter varied from 1 to 3 cm in the various runs; the neutron beam intensity at the scatterer was about 10^4 to 10^5 neutrons cm^{-2} $sec.^{-1}$. The equipment was accurately centered in the beam by the use of x-ray film preceded by a sheet of polyethylene for an intensifier.

An experimental determination of the energy distribution of the neutron beam was made by the method described in NP-1 of desensitizing the last counter of the telescope and varying the amount of tungsten placed in the position of absorber A. Allowing for the dependence of the n-p scattering cross section on angle and energy and for the variation in loss due to different thickness of tungsten at the position of absorber A

we obtain the results given in Fig. 2. For the 200 Mev cutoff used this gives a mean neutron energy of about 260 Mev.

V Conclusion

The normalized values of $\sigma(\Phi)$ for all the runs are given in Table I. The normalization is done as explained before by requiring that

$$\int \sigma(\Phi)\, d\Omega = \sigma_t = 0.035 \times 10^{-24} \text{ cm}^2$$

Since $\sigma(\Phi)$ is not known for the entire range of Φ we have arbitrarily extrapolated $\sigma(\Phi)$; in units of 10^{-27} cm^2 we have put $\sigma(\Phi)$ equal to 3.6 at 75°, 3.0 at 80°, 2.0 at 85° and 0 at 90°. The contribution of the extrapolated part of the curve to σ_t is 15 percent of the total. The value of σ_t has been measured in this laboratory,(4) (5) using two types of detectors; the values of $\sigma_t = 0.035 \times 10^{-24}$ cm^2 has been taken as approximate average of these data. As was explained in Section III of NP-1 this value of σ_t is subject to considerable uncertainty (25 percent) because of the neutron energy distribution and the change of sensitivity with energy for the particular detectors used.

To find $\sigma(\theta)$, the center of mass differential cross section, the value of $\sigma(\Phi)$ must be multiplied by $d \cos \Phi / d \cos \theta$ and the result paired with the value of θ corresponding to the Φ considered. This has been done using the appropriate values of $d \cos \Phi / d \cos \theta$ for neutrons of 260 Mev energy and the results for all runs are given in Table II; the weighted averages of these data are shown in Fig. 3. For comparison we have included in Fig. 3 the previous measurements at 40 and 90 Mev which are shown as stars. The errors given in the tables are the standard deviations calculated from counting statistics only.

---

(4) R. Fox, C. Leith, K. McKenzie, and L. Wouters } to be published in
(5) J. DeJuren } the Phys. Rev.

The weakest points of these experiments are the broadness of the primary neutron spectrum, the uncertainty in the total neutron cross section and the fact that the form of the primary neutron spectrum is not well known. If a better neutron source, e.g., p on d, should be found it would be worthwhile to repeat the whole experiment, possibly with considerable changes in technique (e.g., scintillation counters). In the meantime we have decided to publish the present results even though they are probably less reliable than the ones in NP-I.

This work was done under the auspices of the Atomic Energy Commission.

Information Division
ead/3-8-50

<u>Table I.</u> 260 Mev $\sigma(\Phi)$ in 10^{-27} cm^2 per steradian. All runs have been fitted to run 2, and adjusted to $\sigma_t = 0.035 \times 10^{-24}$ cm^2.

Run Number		1	2	3	4	5	6		
Date	Φ (deg.)	3-10-49	3-23-49	3-31-49	4-7-49	4-14-49	4-21-49	Weighted Average	Trans-mission of Absorber A
	0			62±9				62.0±9.0	.60
	5			29±5			42.0±6.0	35.4±3.8	.60
	10	30±5	28.4±2.2	27±4			29.5±2.6	28.7±1.5	.61
	15		20.5±2.1	20±4				20.4±1.9	.63
	20		17.8±2.0				19.4±2.9	18.7±1.3	.65
	25		11.0±1.6					11.0±1.6	.68
	30		6.1±1.0				9.7±1.7	7.0±0.9	.72
	35		7.0±1.1		7.4±2.0	7.7±1.6	6.1±1.3	6.9±0.7	.76
	40		3.4±0.8					3.4±0.8	.81
	45	5.7±0.8	6.1±0.7		5.9±1.5	5.6±1.2	3.8±0.6	5.2±0.4	.86
	50				4.8±1.7			4.8±1.7	.90
	55				7.0±2.0	2.9±1.0		3.7±0.9	.93
	60					2.0±1.2		2.0±1.2	.95
	65				3.0±1.8	6.0±1.2		5.1±1.0	.96
	70				7.9±2.3	3.7±1.0		4.4±0.9	.97

Table II. $\sigma(\theta)$ (center of gravity system) in 10^{-27} cm^2 per steradian; $\sigma(\theta)$ has been obtained by multiplying $\sigma(\Phi)$ of Table I by the appropriate values of $d \cos \Phi / d \cos \theta$ for neutrons of 260 Mev energy.

Run Number		1	2	3	4	5	6	
Date	θ (deg.)	3-10-49	3-23-49	3-31-49	4-7-49	4-14-49	4-21-49	Wtd. Average
	180			13.7±2.1				13.7±2.1
	169.3			6.4±1.2			9.2±1.2	7.8±0.8
	158.7	6.8±1.1	6.4±0.5	6.1±0.9			6.6±0.6	6.4±0.3
	148.1		4.8±0.5	4.6±0.9				4.7±0.4
	137.6		4.3±0.5				4.7±0.7	4.5±0.3
	127.1		2.8±0.4					2.8±0.4
	116.7		1.7±0.3				2.6±0.5	1.90±0.24
	106.5		2.0±0.3		2.2±0.6	2.3±0.5	1.8±0.4	2.02±0.21
	96.3		1.1±0.3					1.09±0.26
	86.3	2.0±0.3	2.2±0.3		2.1±0.5	2.0±0.4	1.4±0.2	1.85±0.14
	76.4				1.9±0.7			1.9±0.7
	66.6				3.2±0.9	1.3±0.5		1.7±0.4
	56.8					1.1±0.6		1.1±0.6
	47.2				1.9±1.2	3.9±0.8		3.3±0.6
	37.7				6.4±1.9	3.0±0.8		3.6±0.7

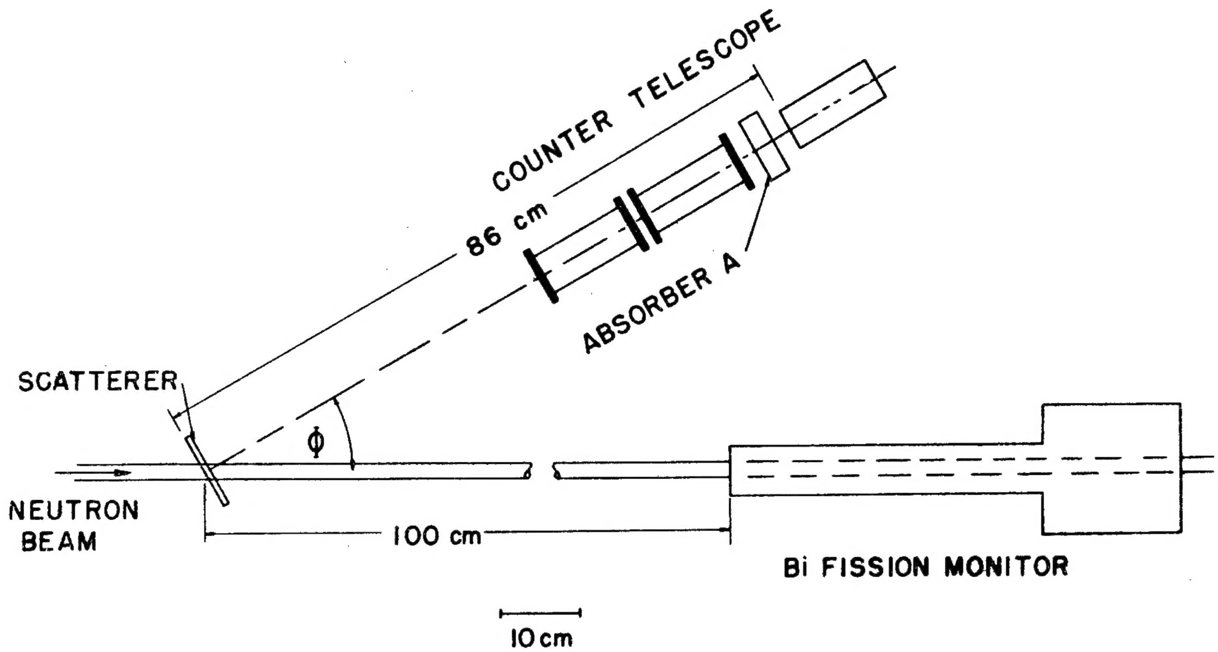

Fig. 1--General arrangement of apparatus.

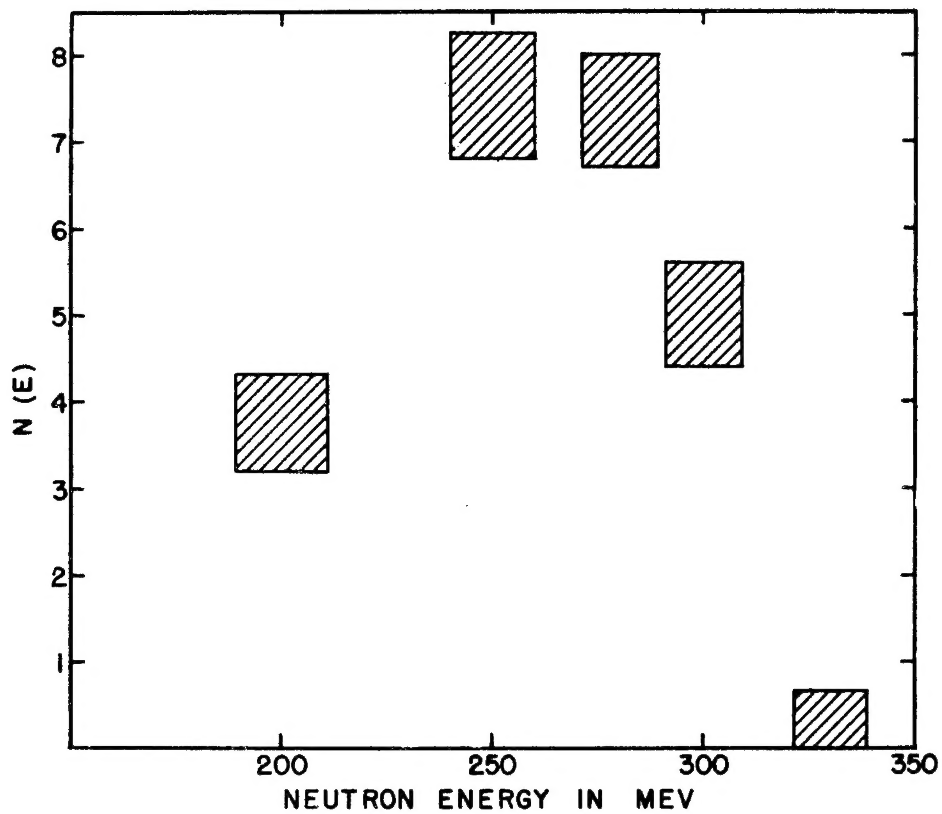

Fig. 2--Energy distribution of the primary neutrons in the beam in the forward direction obtained by 350 Mev protons incident on 5.08 cm thick beryllium. The width of the boxes represents the energy resolution of the detector and the height of the boxes represents the standard deviation due to counting statistics alone.

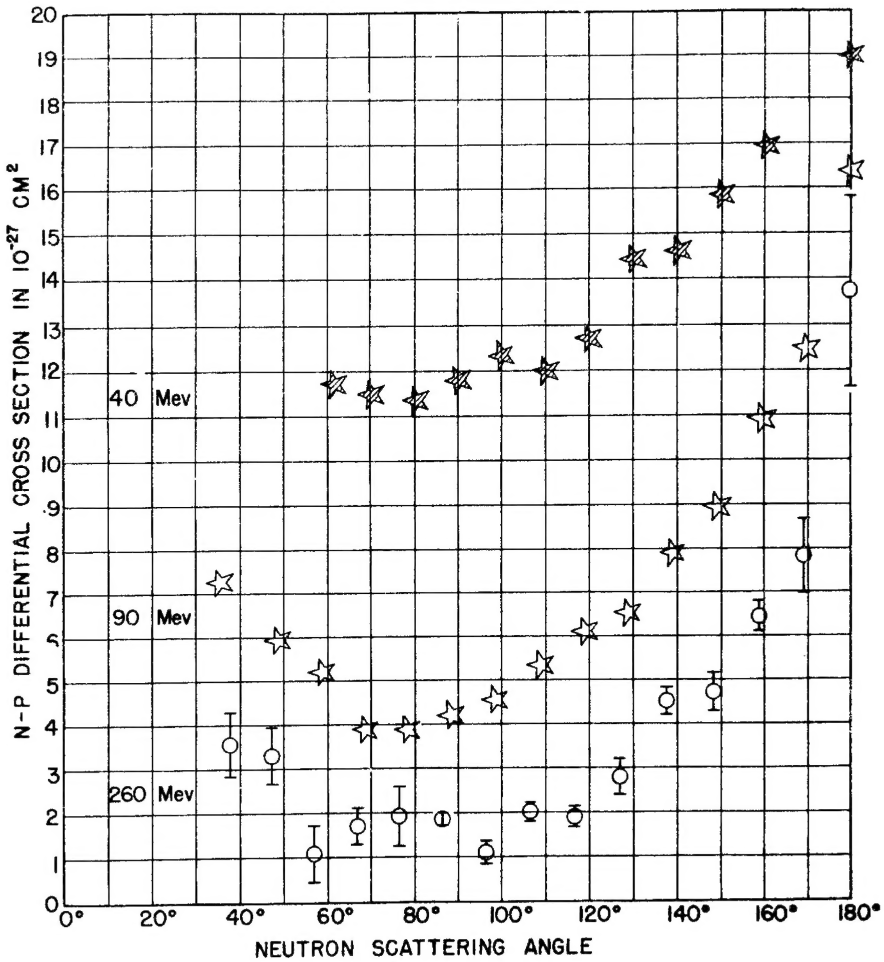

FIG. 3 Mu 57

Fig. 3--Differential neutron proton cross section in the center of mass system in 10^{-27} cm^2 per steradian. The stars represent data published earlier but are included here for reference. The lowest curve represents the data taken with 260 Mev neutrons; the errors given are standard deviations due to counting statistics alone.

END OF DOCUMENT

AEC, Oak Ridge, Tenn., 6-8-50--550-A20010